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LANL Report on Northstar Facility Design Support FY21

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2/4/2022

Introduction

As Northstar enters a stage of rapid progress in the construction and implementation of their accelerator based Mo99 production facility, LANL has been supporting the effort as requested. This support is often an assistance response to issues as they arise. This report will describe these issues and the LANL contribution in analysis, advice and experimentation.

Target Housing Cooling Studies and Design

LANL designed the target over many years and through many changes in requirements. Mainly changes in beam spot size, energy and current. This was done with little attention to the heat loads in the target housing. In the first quarter of FY21 ANL has performed thermal modeling and analysis of the housing. This analysis indicated unacceptably high temperatures. The solution was to increase the total helium flow rate and allow for some bypass flow over all sides of the housing. The housing material was changed to Inconel 718 for added high temperature strength over stainless steel. This was an iterative process over time, with model improvements and refinements. LANL intends to perform a confirmatory analysis and to do flow testing with flow visualization of the bypass flow, this latter work as part of a separate work package.

The helium blower that Northstar has purchased has much greater flow capacity than those used for experiments at LANL and ANL. Total flow through the target is limited by pressure drop. Available head for the target is approximately 21 psi. This limits the flow through the target to about 400 g/s. The blower is capable of up to 500 g/s, so in addition to the 400 g/s in the target, the blower can deliver the 15 g/s planned for flow up the target insertion pipe and additional bypass flows around the housing.

Target Housing Locating and Positioning In-beam

Northstar plans to use locating and centering pins that contact the bottom of the target housing to properly position the target within the beam line. A Northstar image of these pins and their location is shown in Figure 1. LANL worked alongside Northstar engineers to establish a working combination of design and materials.

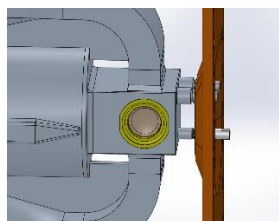


Figure 1. Target locating pins for in-beam centering

Figure 1 shows the inserted target housing, with the helium cooling lines (rectangular) in at the bottom and out at the top. This housing slides down a long pipe through shielding and locates precisely within

the beam pipe, coming into the page and directed to the target window (yellow). The target housing is in the beam vacuum environment. The red plate is part of the fixed structure surrounding the target, essentially a water-cooled box to which the beam pipes attach to allow beam impingement on the target. The alignment and positioning pins enter the vacuum space through the plate, which has cooling water, so one end of the pins is cooled while the other end in vacuum has no cooling but does have some volumetric heating by beam scatter and activation products.

A working solution was found that included improvements to the heat transfer through the pins by optimizing size and minimizing length within the vacuum space. Inconel was chosen over other options, including aluminum. While it has higher density and therefore higher volumetric heating than other options, its high strength and corrosion resistance make it the better choice, in spite of temperatures approaching 700 C.

Preliminary analysis of the mechanical loads pressing the target housing against these stops is showing excessive stress. Some redesign and re-analysis is in progress. The high stress points are limited to a small area with sharp corners. Some fillets in this region may be sufficient to reduce these stresses.

Beamline Jacket Cooling

Related to the locating pin cooling problem was a problem with cooling the beamline jacket. Cooling water for this region first passes down an annulus surrounding the incoming beam pipe in order to cool this section of pipe that sees significant heating because of its proximity to the target. That cooling water then enters a rectangular space called the jacket. This jacket surrounds and encloses the target vacuum containment which is cooled with this water flow.

Beam heating of this jacket is highest directly along the beam line. The water flow leaving the beam pipe cooling annulus impinges at that location, then turns to follow the path toward the locating pins. The high heating in this region results in temperatures above 160 C, based on single phase water, which would cause boiling and possible further overheating if local dryout occurs. As a general rule, boiling is avoided in all regions in or near a target because of the dryout uncertainty and the difficulty and cost of repairs. This geometry and temperature profile is shown in Figure 2.

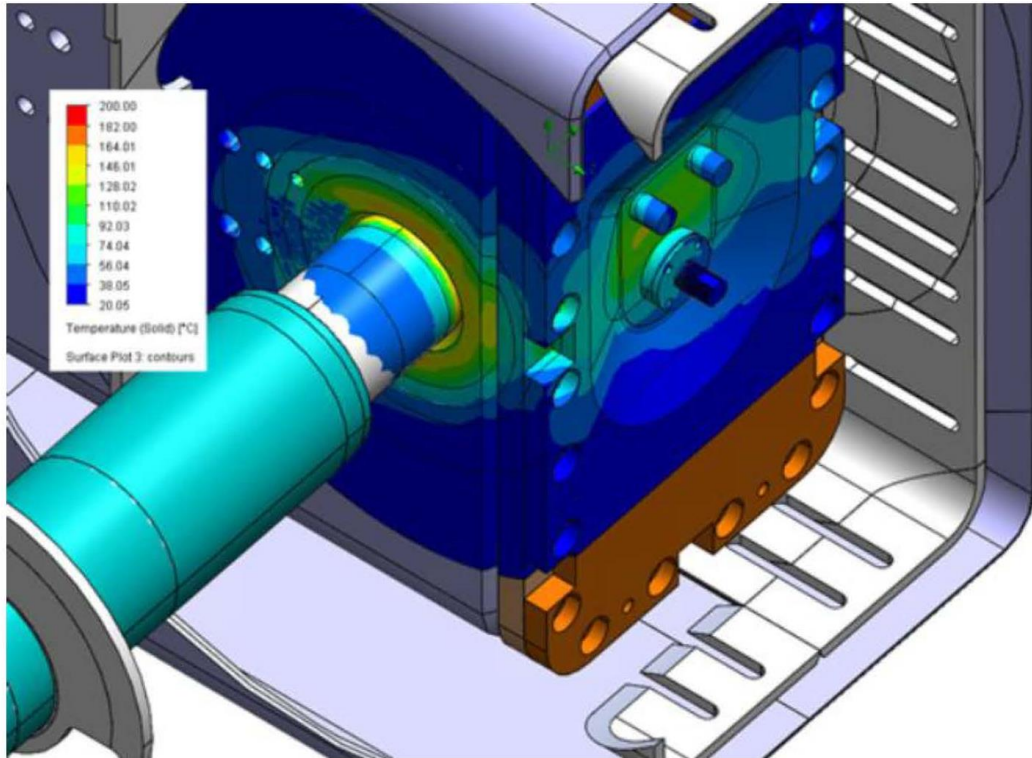


Figure 2. The water jacket surrounding the target vacuum enclosure, showing the beam pipe connection and the resulting temperature profiles.

Heat flux in the region is approximately 86 W/cm^2 , quite reasonable by most standards, but the water velocity was quite low, but with a local peak of 250 W/cm^2 . Inlet water velocity was less than 2 m/s . LANL suggestion was to increase the velocity locally to 10 m/s by funneling the beam pipe water flow directly onto the region of high heat flux. 10 m/s (20 ft/s) is generally accepted maximum for steel and iron piping. This solution was adopted.

Temperature Instrumentation of Local Target Shielding

Temperature measurements in the local target shielding were proposed by Northstar and reviewed by ANL and LANL. These measurements would include the trouble spot discussed above. It is recommended to proceed with caution. Any penetrations for thermocouples must be robust so as to not produce leak points. The areas of interest are in some cases difficult to access. Beyond that concern, any performance data that can be obtained is a benefit.

Temperature Instrumentation of the Housing Exterior

Discussions and preliminary plans to attach some thermocouples on the exterior of the housing are in progress. These lines would be in part uncooled as they traverse the vacuum space but they should be effective and survive the early days when the beam current is low. These results can be scaled to higher beam current when and if they fail.

Pressure Relief Valve Settings and Test Pressure

Northstar will soon be receiving their helium blowers. This has initiated a discussion of relief valve setting as well as window pressure test setting. As often occurs, there has been some confusion over terms: Operating pressure, design pressure and maximum allowable working pressure.(MAWP). MAWP is a calculated number that is the pressure that results in the object (the window being the object of weakest pressure rating) being at the maximum code allowed stress state. Design pressure is as implied, the pressure at which the window was designed to handle within Code requirements. Operating pressure is wherever the window is operating at any given time. This can be no more than design pressure and is not relevant to pressure Code standards. In this case, the design pressure and the MAWP are taken to be the same value: 300 psia, or 285 psig.

MAWP is a calculated number based on a Code allowable stress for the material at the temperature of operation. This is typically, and for Inconel, $UTS/3.5$. Stainless steels are an exception: $2/3$ yield. Code requires a pneumatic pressure test at 110% of design pressure or a hydro test at 150%, with temperature correction based on UTS.

Design pressure is always equal to or less than MAWP, usually 10% or 15 psi below (if I recall correctly) for the reason you are concerned about: PRV opening at too low a pressure. Unfortunately the window was designed by analysis with the Code allowable stress as the gold ring, so to speak. So with the He pressure at the window 300 psia you are at MAWP (with its 3.5 factor of safety on failure).

So, plan on 285 psig maximum blower discharge pressure. What your supplier is saying about relief valve opening is contrary to what I think I know. The valve can certainly start opening below the set point, but is not fully open until some value greater than set point. I am not recalling that at the moment but 10% comes to mind. But we should assume your vendor knows his product so take his guidance on that.

You want the blower discharge pressure at 285 psig to insure 300 psia at the window. The relief valve will crack open at less than the set point, so the set point needs to be 330 psig as you say. This puts you above MAWP. There is a generous safety factor on that. You could raise the pneumatic test pressure to 440 psig.

Target Holder Laminations Cooling

The target disks are held between laminations which are pinned together as indicated in Figure 2. Analysis showed that the outer reaches at the pins holding the stack were excessively hot. Northstar has incorporated some flow channels for improved cooling of the laminations. Analysis by engineer at ANL indicates that this is effective and sufficient. LANL will be performing similar analysis as a confirmation. Some changes to accommodate additional bypass flow in these areas may be advisable.

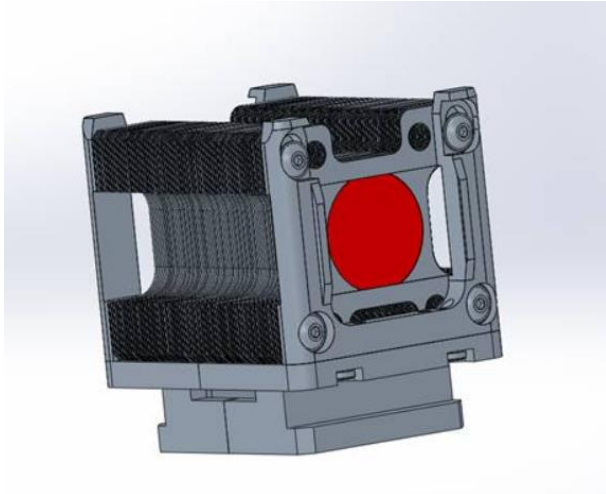


Figure 2. Lamination stack-up.

IR and OTR Operation Issues

Experiments performed by LANL at ANL were instrumented by IR and OTR cameras aimed at the window. The OTR images the placement and size of the beam, the IR indicates window temperature profile. Northstar intends to use these same diagnostics to monitor the facility beam and window. A very conceptual illustration of the arrangement is shown in Figure 3. Preliminary discussions were held between LANL and Northstar on March 16, with the following points of note:

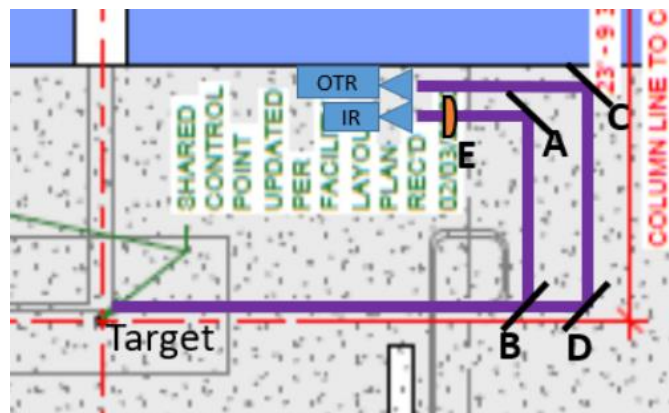


Figure 3. Conceptual layout of the OTR and IR cameras within the target tunnel.

In situ calibration of the IR camera setup is extremely important. Small changes anywhere in the system can impact the measurement, particularly tilt angle of mirrors and emissivity of the window surface.

Keep the line of sight as direct as possible.

Use as large a lens as available and have the vendor (FLIR) calibrate the lens.

Because of the high beam current of the facility as compared to experimental work at ANL, the brightness of the optical signal to the OTR camera may be a problem. Filtering may be required.

An overarching concern is radiation damage limiting the life of the costly IR camera. LANL suggested the following considerations and changes:

Move the cameras as far as possible from the target. For example, the distance from target to camera is increased without increasing total separation distance by flipping the camera location 180° in the view shown in Figure 3.

Generate detailed radiation dose and type information for the camera location and design shielding specific to that location. Investigate specific radiation effects on this type of camera.

To simplify replacement of a camera, consider moving the camera placement into the rhodotron vault. This would eliminate mirrors A and C in Figure 3 and place the cameras on the opposite side of the blue wall in the figure. This placement is most likely also better shielded.

Continuous IR measurement data may not be necessary. Consider having a movable shutter to block radiation down the line of sight. Having the camera imaging the window perhaps 5 minutes every 2 hours reduces the direct exposure to about 4%.

As the year has finished, Northstar has a plan for camera use but has not involved LANL in the discussion.

Additionally, the window surface finish in regards to brightness is an issue. A bright, reflective surface is preferred for OTR while a duller finish, higher emissivity, is preferred for the IR. Suggestion is to leave the window as provided by the machining process. The emissivity should be in the range around 0.3, which will be acceptable for both measurements.

Target Window Material, Surface Finish and Weldment Issues

LANL had specified annealed Inconel 718 for the window material. This specification was questioned, with the suggestion that precipitation hardened material is a better choice based on material strength.

The LANL position is based on a history of using more ductile annealed material for proton beam windows because of inevitable radiation hardening. The Northstar electron beam however will produce virtually no radiation hardening of the window. After deliberation and discussion with materials specialists, it was agreed that the precipitation hardened material is preferred for this application. Ideal hardening is nominally 1 hr at 1750 F followed by water quench.

For the window weldment to the housing, LANL had been using e-beam welds. Northstar was having difficulty finding capability for this process locally and suggested laser weld. Laser weld is acceptable. It should be noted that the design of the window mount to the housing has changed so that now the weldment is further from the actual window surface. At this location, a good TIG weld would be acceptable. The motivation for e-beam or laser weld is to minimize the heat affected region and minimize distortions of the window. This is less important, but e-beam weld is preferable to TIG nonetheless.

Window surface finish has also been discussed. A 32 RA is reasonable and appropriate. This should give good optical properties for OTR and IR cameras and not in any way compromise the window by additional polishing.

Window Cooling Tests

The baseline window cooling tests are part of this work package. This baseline is with a 0.5 mm helium coolant gap between the window and the first disk. These tests were completed. Measured power in the window by helium calorimetry was 1800 W, in excess of the 1360W expected as per MCNP analysis of the electron beam attenuation in the window. Mass flow rate in the window channels is 32.4 g/s, as per ANSYS finite element analysis. Initial tests showed window distortions and damage but no leak. Subsequent testing on repaired parts and new window indicate adequate cooling and window performance. These tests were performed with 2000 W power in the window, with no detrimental effects or observations.

Concluding Remark

LANL continues to support Northstar as they approach production-ready. In addition to the highlights described above, LANL provides guidance and opinions via bi-weekly meetings and a steady exchange of email communications as issues arise.